At 10:30 a. m. the sun's altitude was about 34° 30'. The results of the meteorological observations made on these mornings in Tokyo are as follows:

Atmospheric condition on January 30 and February 17, 1914.

January 30, 1914.

Elements.	1 a. m.	2 a. m.	3 a. m.	4 a. m.	5 a. m.	6 a. m.	7 a. m.	8 a. m.	9 a. m.	10 a. m.	11 a. m.	Noon.
Pressure (mm.)	756.8	756.9	756.9	756.9	756.8	757.2	757.7	757.9	758.0	758.0	757.6	756.6
Air temperature (° C.)	−1.6	−1.8	−1.3	−1.8	−2.4	−2.5	−2.5	0.2	2.9	5.9	7.4	9.0
Relative humidity (per cent)	90	90	85	85	87	80	82	70	65	53	51	44
Vapor pressure (mm.)	3.7	3.6	3.5	3.4	3.3	3.0	3.1	3.3	3.6	3.7	3.9	3.8
Wind direction	SSE.	SSE.	W.	W.	W.	W.	W.	W.	W.	W.	NNW.	NE.
Wind velocity (m/s)	1.1	1.3	2.4	2.0	1.5	1.5	1.3	1.6	1.5	1.5	2.4	2.2

February 17, 1914.

Elements.	1 a. m.	2 a. m.	3 a. m.	4 a. m.	5 a. m.	6 a. m.	7 a. m.	8 a. m.	9 a. m.	10 a. m.	11 a. m.	Noon.
Pressure (mm.)	766.4	766.4	766.2	766.2	766.7	766.5	766.6	766.7	766.7	766.4	766.1	765.5
Air temperature (° C.)	2.4	2.6	2.8	2.1	0.6	−0.4	−0.2	3.0	5.2	7.9	11.6	11.2
Relative humidity (per cent)	98	98	96	98	96	95	95	94	79	67	60	60
Vapor pressure (mm.)	5.3	5.4	5.4	5.2	4.6	4.2	4.3	5.3	5.2	5.3	6.1	6.2
Wind direction	NE.	NE.	N.	N.	N.	N.	N.	N.	N.	N.	NNW.	NNW.
Wind velocity (m/s)	1.5	1.5	1.1	1.3	1.3	1.3	1.3	0.8	1.5	0.8	1.8	2.8

In the above tables the air pressure is not reduced to sea level, but only to freezing point.

3. *Horizontal rainbow on March 17, 1914.*—On this morning the sky was so clear that we observed not a single speck of clouds and the air was comparatively calm. At the surface of the same moat we observed a horizontal rainbow from 8:30 a. m. until 9:20 a. m. But on account of ripples on the surface of the moat we could observe no more after 9:20 a. m.

In the narrower part of the moat, which was nearer to [it ?] the north side of the bow was very distinctly visible. We could not measure the width of the bow with much accuracy, but the value estimated was about 3°.

In conclusion, the author wishes to express his hearty thanks to Dr. T. Okada for his kind guidance.

THE HALOS OF NOVEMBER 1 AND 2, 1913.

By Dr. LOUIS BESSON.

[Dated: Observatoire de Montsouris, Paris, April 21, 1914. Translated by C. Fitzhugh Talman, Professor of Meteorology.]

Some remarkable optical phenomena of the class of halos and parhelia were seen in the eastern half of the United States on November 1 and 2, 1913. On the 1st, there was observed at many places the halo of 22° radius, in some cases brilliant and accompanied by the parhelia pertaining to it, but the phenomenon appears to have attained abnormal complexity only in a rather limited region, comprising southwestern Missouri and extreme northeastern Arkansas. At Springfield, Mo., according to Mr. J. S. Hazen, Local Forecaster, "this unusual and remarkable phenomenon excited a great deal of interest and comment among all classes and the office had more than a hundred calls during the day concerning the phenomenon."

The following day, optical phenomena no less remarkable, and of a very similar aspect, were again observed, but this time at a great distance to the eastward, in the states of Virginia, West Virginia, and Maryland. In a letter to the editor of the Scientific American, Dr. E. C. L. Miller, of the University College of Medicine at Richmond, Va., says that the phenomenon was very complex and striking at that place. It was doubtless equally so, he adds, "in a considerable area, for several inquiries were received by the railway companies from their station agents out on their lines as to the cause of the phenomena."

From inquiries made by Prof. J. Warren Smith at Columbus, it appears that in Ohio several persons observed brilliant and persistent halos on the 1st and 2d, as well as parhelia and other less common appearances, but that the phenomenon was less generally observed and probably less well developed in that region.

METEOROLOGICAL CONDITIONS ACCOMPANYING THE PHENOMENA.

Brilliant halos often precede or accompany atmospheric disturbances. Those of November 1 and 2, however, were produced under typically anticyclonic conditions, and were not followed by bad weather. A center of high pressure was over Iowa on October 31, over Indiana, November 1, and over West Virginia, November 2. Not much information is at hand in regard to the movement of the ice clouds in which the optical phenomena were produced. At Springfield, at 10:30 a. m. of the 1st, the clouds were of the cirro-stratus type, and were moving from the northwest. At 11:30 their appearance was that of alto-stratus, moving from the west, and about 3 p. m. they became stratus, from the same direction. This progressive descent of the clouds leads Mr. Hazen to say that "the downward movement of the ice particles, from which the halo resulted, was evidently large," and that "it is probably true that ice particles, which may result in halos, have a greater or less downward movement, and it is suggested that the more complex forms of halo may be due to large ice particles and consequently greater downward movement or velocity." This opinion is entirely in accord with that which I expressed in 1909 in my thesis "Sur la théorie des halos,"[1] in consequence of a large number of similar observations.

HALOS OF NOVEMBER 1.

Mr. J. S. Hazen, Local Forecaster, Weather Bureau, has furnished a detailed description and a drawing of the phenomenon observed at Springfield, Mo. This drawing, reproduced in figure 1, is a combination of three different sketches made during the rather long duration of the halo; it does not, therefore, relate to a definite time and elevation of the sun. The part of the phenomenon which attracted most attention was a wide ring, *A*, half a degree

[1] Annales de l'observatoire de Montsouris, 1909, 10: 161.

in width, passing through the sun and running around the sky parallel to the horizon (parhelic circle). This was visible from 11 a. m. to 1 p. m. At times, about noon, "portions of this circle shone out with dazzling white light, from an apparently clear sky." Around the sun were seen the halo of 22°, *H*, and the circumscribed halo, *D*, both complete, colored, and "of unusual brilliance." The halo *H* is in reality a circle, and the halo *D* a sort of ellipse, but, in consequence of an illusion, of which many instances have been recorded, they were mistaken for two intersecting circles, as shown in the drawing. Mr. Hazen notes a remarkable extension of the prismatic colors at *a* and *b*, inside the space bounded by dotted lines in the drawing. Besides the circumscribed halo, a second colored arc, *G*, was tangent to the halo of 22° at its lowest point. The parhelia, *P*, *P*, described as brilliant, are shown in the drawing outside the circumscribed halo; normally they should have been inside, since the altitude of the sun did not exceed 32° 24′. A white light-pillar, *E*, marked the vertical diameter of the halo of 22°. The upper half of the halo of 46°, *C*, was visible. The parhelic circle showed, at *x*, *y*, *z*, spots of greater illumination, of which the first, *x*, was the anthelion, and the other two, *y* and *z*, were paranthelia, which the drawing places 45° in azimuth from the anthelion. One might assume these to be the ordinary paranthelia, the vertical distance of which from the anthelion is 60°, but in that case the small arcs which pass through them, and which appear to belong to a circle having its center at the anthelion, would constitute something entirely new. From the anthelion proceeded two white arcs, *B*, *B*, directed obliquely toward the region of the sun. This is a rare and interesting appearance, known under the name of "oblique arcs of the anthelion." We shall return to this subject later.

In reply to a request for further information, the observer states that "the spots, *x*, *y*, *z*, were not distinctive in their characteristics and had more the appearance of a diffused tail to a comet than a distinct arc of a circle, though it was assumed at the time that there were probably such arcs at *y* and *x*, and a convex segment at *x*. There was a faint suggestion of color, through smoked glasses, at *y* and *z*, but none at *x*." The arcs, *B*, *B*, "were not observed until about noon and only for a short time." In his description of the phenomenon, Mr. Hazen speaks of a "white spot in the southwest" which is not shown in the drawing.

At Galena, Mo., the phenomenon was visible between 11 a. m. and noon, and Mr. H. McGrew made a drawing of it, which has been forwarded by Mr. Hazen. There is here seen (fig. 2) the halo of 22°, with a bright spot at the top; the parhelic circle ending at the halo; the two ordinary parhelia (which are shown in the drawing in the circumference of the halo, from which they should have been 3 to 5 degrees distant); two paranthelia, 39° from the anthelion, which is here only shown as the point of intersection of two oblique arcs, shorter than those seen at Springfield; finally, traces of a vertical light-pillar inside the halo of 22°. Elevation of the sun, 37° to 39°.

At Bentonville, Ark., according to Mr. Parker, Assistant Observer, U. S. Weather Bureau, the phenomenon was visible from 8 a. m. to 11 a. m. It was "almost exactly the same as seen at Danzig in 1661, excepting that there was no trace of a mock sun at the western extremity of the horizontal circle." (This refers, no doubt, to the anthelion.) "At times the horizontal circle was complete, but mostly portions of it were obscured by thin clouds. The upper arc above the sun was remarkably bright." Mr. Parker's sketch, reproduced in figure 3, is intended to represent the appearance of the phenomenon at 10:30 a. m., but I think that certain particulars were really seen earlier, and no longer existed at that time. Thus the very brilliant tangent arc, at the summit of the halo of 46°, can hardly be other than the circumzenithal arc, the appearance of which is normally impossible when the sun is 35° above the horizon, which was its altitude at 10:30 a. m. The paranthelia are situated in their theoretical positions, 120° from the sun on the parhelic circle. The western one, which was not obscured by lower clouds, was brilliant. Both of them are crossed by arcs which, in my opinion, very probably belong to the halo of 90°, known as the "halo of Hevelius." In fact, with a solar elevation of 35°, the halo of 90° radius cuts the parhelic circle almost exactly at 120° from the sun. Lastly, there are seen in the drawing parhelia of 46°, described as "bright," and shown exactly on the corresponding halo.

At Bentonville, Mr. E. H. Jacobs made, apparently with great care, four drawings of the phenomenon; viz, at 8 a. m., between 8:30 and 9 a. m., at 9:30 a. m., and at 11:30 a. m. Solar elevations: 14°, 19° to 24°, 28°, and 39°. In two of these drawings (figs. 4 and 6) are seen the parhelia of 46° without the corresponding halo, an interesting observation, confirming the real and independent existence of these parhelia, which has long been a matter of doubt. Between 8:30 and 9 a. m., with solar elevation between 19° and 24°, the halo of 46° was visible. In the drawing (fig. 5) it passes exactly through the parhelia. At the summit of this same halo is seen the circumzenithal arc, the red portion of which is shown in coincidence with the blue of the halo.[2] This lack of tangency of the bands of corresponding color in the two luminous arcs is real, and increases in proportion as the sun moves away, either upward or downward, from the altitude of 22°, at which there is exact tangency between the arcs. With a solar elevation of from 19° to 24°, the maximum departure from tangency is only 0° 19′, and would be quite difficult to observe. The first two drawings show in the southwest, 90° from the sun in azimuth, parhelia crossed by an arc of the halo of Hevelius, the halo being described as "white and bright." On the last drawing (fig. 7), made at 11:30 a. m., are seen only, in the north, an arc of the parhelic circle, and, 13° (?) below, a parallel arc, "very dim," which is doubtless to be classed among the phenomena which Bravais has termed "extraordinary parhelic circles."

At Neosho, Mo., between 8:30 and 10 a. m., Mr. H. G. Geyer observed the halo of 22° and its upper tangent arc, both brilliantly colored, the ordinary parhelia, an incomplete parhelic circle, a "dog" in the north on this circle, "at right angles to the sun" (paranthelion of 90°), and "in the west another bright spot, which would be on a continuation of the bright streak" (probably the anthelion); finally, "nearly overhead, an arc of about 30°" (doubtless the circumzenithal arc, or the upper part of the halo of 46°).

HALOS OF NOVEMBER 2.

Dr. E. C. L. Miller observed the phenomenon at Richmond, Va., where it was particularly well developed. He furnished to the Scientific American a careful drawing (fig. 8) and a good description, as follows: "I first noticed the phenomena about noon and they remained visible several hours. The most marked object was a large circle about 30 degrees above and concentric with the horizon. It was white and about the width of the full moon. On this circle there were four bright chromatic nodes marked

[2] The original drawing is tinted to show this.

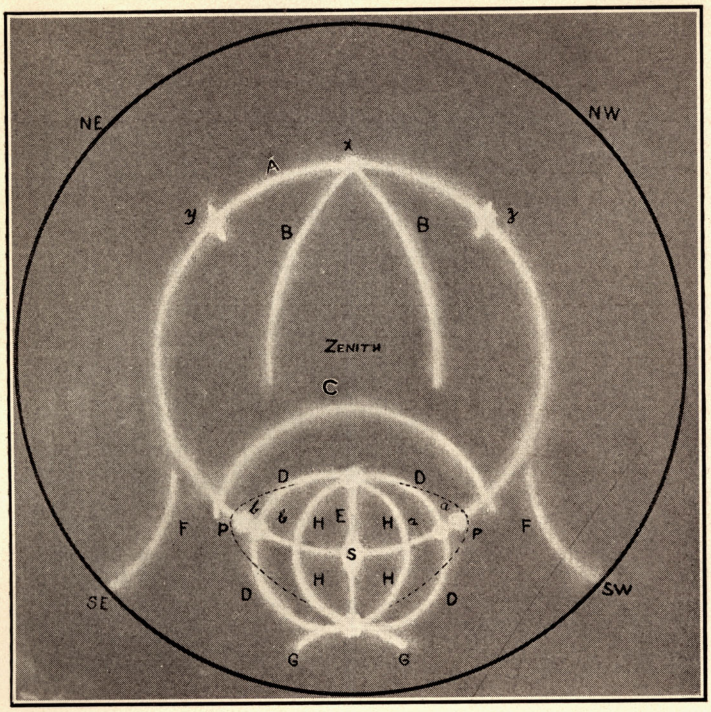

FIG. 1.—Composite drawing of halos observed at Springfield, Mo., Nov. 1, 1913, by J. S. Hazen. (No definite time or solar altitude.)

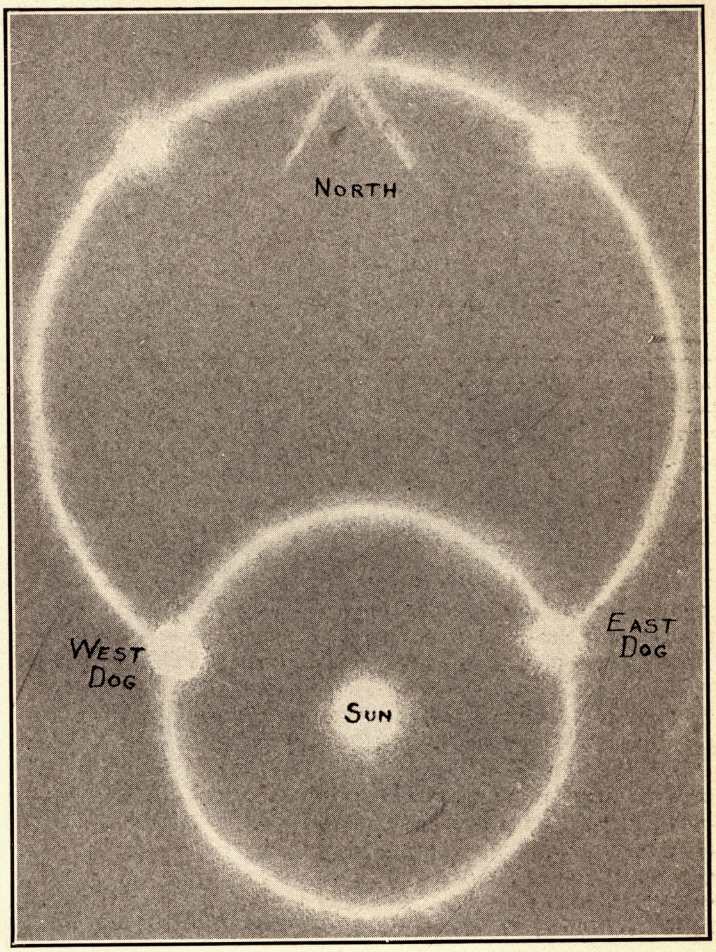

FIG 2.—Halo seen at Galena, Mo., Nov. 1, 1913, by H. McGrew. (Time: 11 a. m. to noon; solar altitude: 37°-39°.)

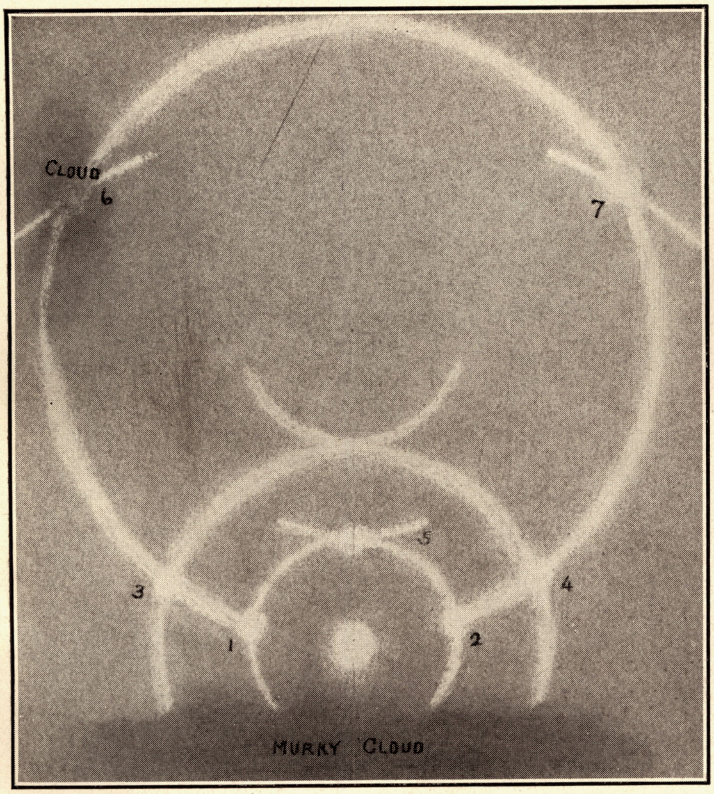

FIG. 3.—Halo seen at Bentonville, Ark., by Orin Parker on Nov. 1, 1913. (Time: 10:30 a. m. [?].)

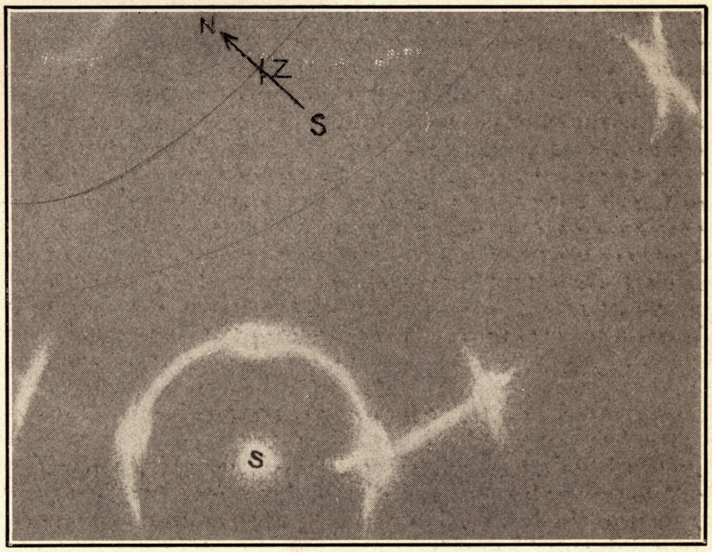

FIG. 4.—Halo seen by E. H. Jacobs at Bentonville, Ark., Nov. 1, 1913. (Time: 8 a. m.)

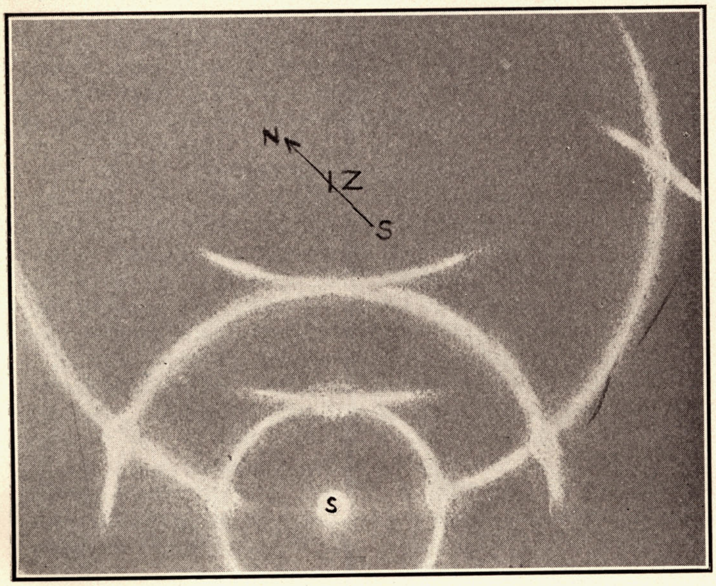

FIG. 5.—Later stage of figure 4 (8:20-9 a. m.).

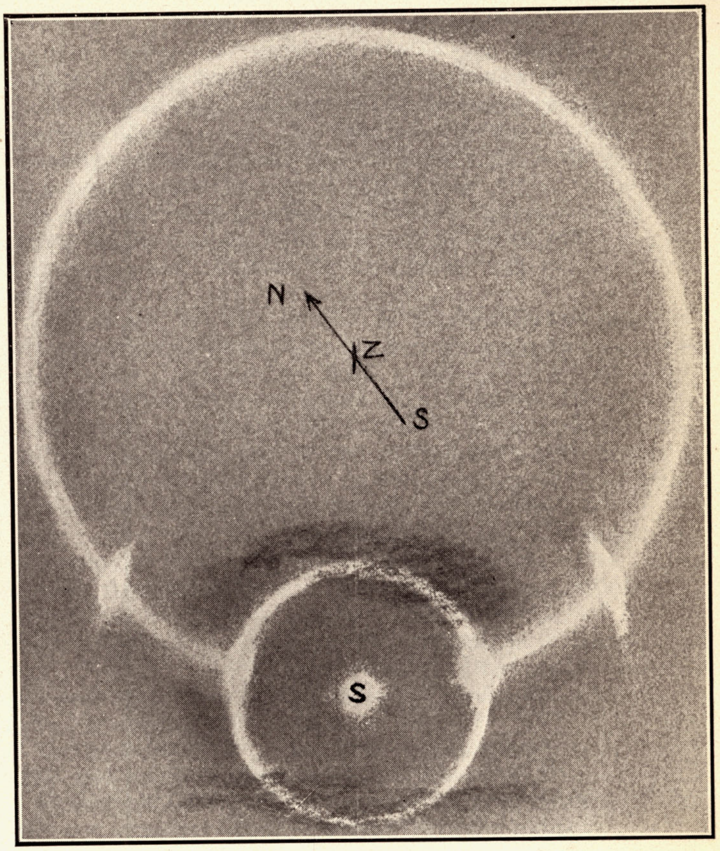

FIG. 6.—Later stage of figure 4 (9:30 a. m.).

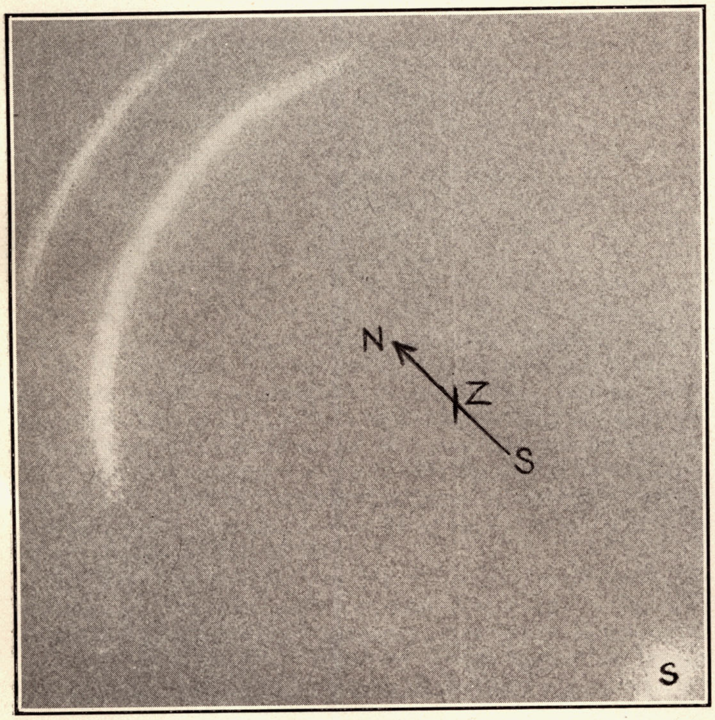

FIG. 7.—Later stage of figure 4 (11:30 a. m.).

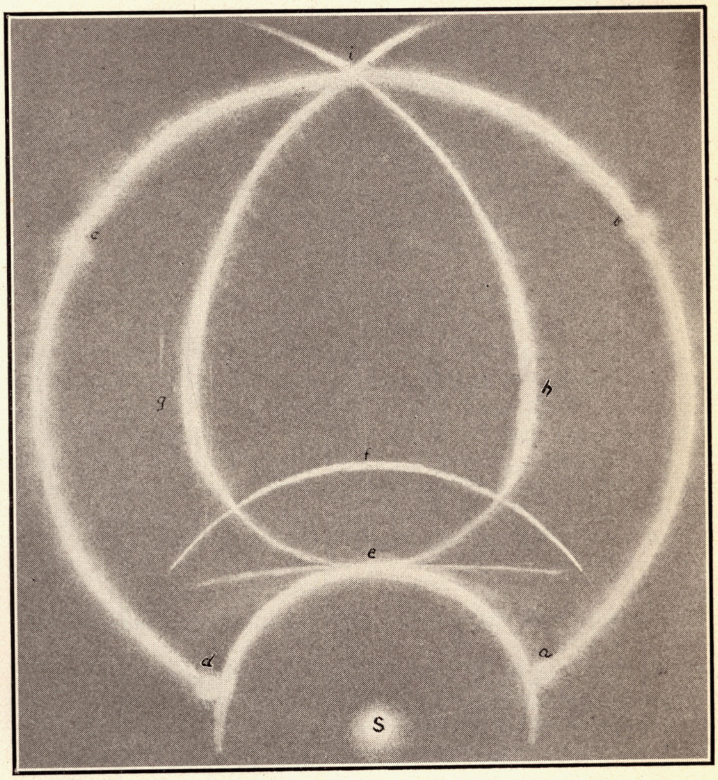

FIG. 8.—Halo observed at Richmond, Va., on Nov. 2, 1913, from noon onward for several hours, by Dr. E. C. L. Miller. (Redrawn from "Scientific American.")

on the accompanying drawing *a*, *b*, *c*, *d*. About the sun there was a marked but not unusual halo strongly chromatic at the point *e*, and gradually fading away toward each side as shown. There was a second concentric circle at *f* also chromatic. From the point *e* tangents extended out on each side as shown. Perhaps the most unusual part of the picture were the lines *ig* and *ih*. They were white, about the same width as the large circle and very clearly seen from *i* to *g* and *h*. Beyond *g* and *h* they became very faint but seemed to curve in to the point *e* as shown. On the attached sketch *s* represents the sun and *o* the zenith * * *.

"* * * The day was beautiful, an ideal autumn day; cool and clear with a slight haze in the air and a bit of herring-bone effect in the sky at times. There were no clouds except very low down and the geometrical designs traced in the sky were very striking. With some crude instruments Dr. Hopkins and I measured the angles as best we could and the drawing is fairly accurate."

In this drawing we recognize the halo of 22° and its upper tangent arc; ordinary parhelia, *a*, *d*, a little outside the halo, which is according to rule; the upper part of a halo of 46°, *f*; the parhelic circle, with the paranthelia of 120°, *b*, *c*, situated within a degree or so of their theoretical position; and, finally, a pair of oblique arcs of the anthelion, *ig* and *ih*, which seem to come together again at the summit of the halo of 22°. No anthelion.

At the Local Office of the Weather Bureau in Richmond, Mr. E. A. Evans, Section Director, observed only the parhelic circle, the ordinary parhelia with lateral portions of the halo of 22°, and paranthelia (of 120° ?), which appear to have been crossed by arcs presenting "faint intermittent red to blue colors" and whose center would appear, from the observer's sketch, to be on the side of the sky opposite the sun. This would be somewhat analogous to what was observed the previous day at Springfield.

Six miles north of Richmond, Dr. E. G. Williams made a sketch of the phenomenon at 1:15 p. m., in which are seen the halo of 22°, the ordinary parhelia, the parhelic circle, and, in the north, on this circle, two spots of white light. From the more easterly of these radiate upward two almost straight streaks of light, marked "rainbow." These might perhaps have been the anthelion with its oblique arcs, the positions of which in the sky not having been very accurately estimated. In this case, the second spot of light would be the western paranthelion of 120°, which might have been the only one visible. According to this hypothesis, which appears to me to be the most probable, the oblique arcs of the anthelion must have been colored, if this interpretation may be drawn from term "rainbow," by which the observer describes them.

At Warrenton, Va., according to Miss Isabel Gaskins, the halo was not so completely developed. She observed only the halo of 22°, with a short upper tangent arc; the upper quarter of the halo of 46°, and the circumzenithal arc, both of the latter very brilliant; the ordinary parhelia; and, lastly, part of the parhelic circle, commencing at the western parhelion and terminating in the east by a "sun dog" (paranthelion of 120°).

At Dale Enterprise, Va., Mr. L. J. Heatwole made the sketch of the phenomenon shown in figure 9. The largest of the three circles, central at the sun, is undoubtedly the halo of 46°. The two others appear to be the limits of the halo of 22°, which must have appeared very broad. The elliptical appendages of the intermediate circle were probably parhelia. The oblique arcs of the anthelion are shown in the form of an ellipse, appearing to have its second vertex about at the upper point of the halo of 22°. These arcs were "light yellow," while the parhelic circle was "snowy white." Mr. Heatwole also sends a cutting from the Pendleton Times of Franklin, W. Va., containing a description of the same phenomenon, observed about noon. In this description we note the following passage, according to which the oblique arcs came together at the sun: "Inside this circle" (the parhelic circle) "was a pointed elliptic figure, formed by similar white clouds, with the sun as its starting point, extending inside and to the northern rim of the large circle."

At Philippi, W. Va., Prof. J. D. Dadisman saw halos of 22° and 46°, with their parhelia, and the complete parhelic circle; also, opposite the sun, a sort of rainbow with paranthelia at the point where it met the parhelic circle; a tanget arc exterior to the latter at the position of the 'anthelion (oblique arcs of the anthelion ?); and, lastly, a 'broad, pale straight line of light" crossing the sky from east to west and passing through the zenith.

At Elkins, W. Va., the aspect of the phenomenon, opposite the sun, appears to have been the same. Mr. Howell, Assistant Observer, Weather Bureau, observed, from 12:05 to 12:58 p. m., the parhelic circle "of bright color, resembling cirrus clouds, brightest opposite the sun. * * * Mock suns were observed in the northeast and in the northwest, where the arc of a secondary halo intersected the primary one. * * * The arc of the secondary ring was less bright than the primary ring, and rainbow tints were not observed."

At Staunton, Va., the phenomenon presented a rather different aspect. Mr. J. C. Darnall made a drawing of it, in colors, at 1 p. m.; this is reproduced schematically in figure 10, where *h* is the halo of 22°; *c*, the parhelic circle, represented as prismatically colored (?); *p*, a parhelion of 22°; *p'*, another colored parhelion (of 46° ?); *A*, the infralateral arc of the halo of 46°, which was brilliantly colored.

At Baltimore, Md., the same infralateral arc was visible from 2 to 4 o'clock, and was very bright. Generally taken for a rainbow, it was widely noticed by the people, while the other parts of the halo passed unobserved. At Takoma Park, Md., Mr. L. M. Mooers, Cooperative Observer, saw only the parhelia, the summit of the halo of 22°, also in the form of a parhelion, and fragments of the halo of 46°.

At Braehead, near Fredericksburg, Va., according to a sketch made at 2 o'clock or a little later, by Mr. S. G. Howison, the phenomenon included the halo of 22°, the ordinary parhelia, the halo of 46°, the circumzenithal arc, and a luminous cross limited by the halo of 22°.

At Washington, D. C., Mr. W. E. Hurd, assistant at the observatory of the Weather Bureau, observed, at 4 p. m., the same phenomena, without the cross, but with the upper tangent arc of the halo of 22°. Prior to 4 p. m. only the ordinary halo and the parhelia had been visible.

BRIEF EXPLANATION OF THE OBSERVED PHENOMENA.

The luminous phenomena that we have just described were produced by the reflection and refraction of light from the sun by lofty clouds consisting of ice crystals. The greater part of these phenomena can be explained in a detailed manner, with a high degree of certainty. For others the theory generally accepted is still incomplete or doubtful. Lastly, certain others, very rare and ill-defined, thus far escape any precise explanation. In nearly all known forms of ice crystals are found faces which meet at angles of 60° or 90°. The refraction of light in these prisms gives a maximum luminosity at 22° or 46° from the sun in all directions. Such is the explanation of the halos of 22° and of 46°.

In order to explain the other phenomena, it is necessary to assume ice crystals of a particular form, oriented in a definite manner by the resistance of the air opposed to their fall. Ice crystals often have the form of elongated right hexagonal prisms. In this case they fall horizontally, as shown in figure 11, and we may perfectly explain the ordinary tangent arcs of the halo of 22°, as well as the circumscribed elliptical halo, by the refraction of the solar rays which enter by a face, m^1, and emerge by a face, m^3, constituting with the former a prism of 60°, with horizontal edge. Moreover, the refraction of the rays which enter by a vertical base, a, and emerge by a lateral face, m, explains the infralateral arcs of the halo of 46° (arcs F F, of fig. 1). If the rays enter by a face, m, and emerge by a base, we have the supralateral arcs, which appear not to have been seen on November 1 and 2.

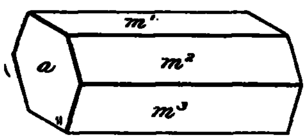

FIG. 11.—Elongated right hexagonal prism of ice, in horizontal position. (Much enlarged.)

Other phenomena are produced by hexagonal prisms oriented vertically. To fulfill these conditions it is necessary that the prisms present, at one of their extremities, a projecting plate, which plays the rôle of a parachute. Among the observed forms, that represented in figure 12 appears to be the most effective. The refraction of the rays which enter by a face, m, and emerge by a face, m^3, gives rise to the ordinary parhelia of 22°. Those which enter by the upper face and emerge by a lateral face, m, produce the circumzenithal arc (observed by Mr. Jacobs at Bentonville, fig. 5). The two forms of ice crystals just mentioned, those which we shall describe presently, and many others, present vertical faces. The simple reflection of the solar light on these faces gives us the parhelic circle. Vertical light-pillars passing through the sun are explained by multiple reflections on lamellar crystals, oscillating round the horizontal position.

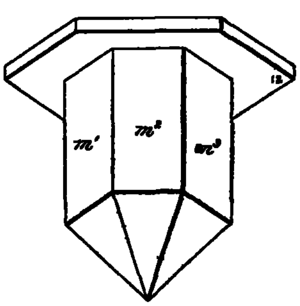

FIG. 12.—Ice crystal consisting of pyramidally terminated hexagonal prism attached to a tabular prism which acts as a parachute when the combination is falling through the air.

Now we come to phenomena whose explanation remains hypothetical. The anthelion can hardly be formed except by double reflection on faces making an angle between them of 90°. Figure 13 shows one of the possible modes of its production. For the paranthelia of 120°, the vertical faces must form an angle of 60°, or of 120°, as in figure 14. No forms of ice crystals now known furnish an explanation of the white paranthelia seen at 90° from the sun, nor of the halo of Hevelius, which is associated with them (observed by Mr. Jacobs at Bentonville, figs. 4 and 5). In the assemblages of prisms such as are shown in figures 13 and 14, the refraction of the rays which enter by a vertical face and emerge by another vertical face, making with the former an angle of 90°, might be the cause of the parhelia of 46° (observed by Mr. Jacobs at Bentonville, fig. 4). In order to explain the extraordinary tangent arcs at the lower point of the halo of 22°, such as the arc GG of the Springfield observation, figure 1, there has been invoked, without much success, the refraction of rays entering by a vertical face, m (fig. 12), and emerging by the opposite face of the lower pyramid. We have still to discuss in some detail a last form of halo, which is for several reasons the most interesting of all those observed on November 1 and 2.

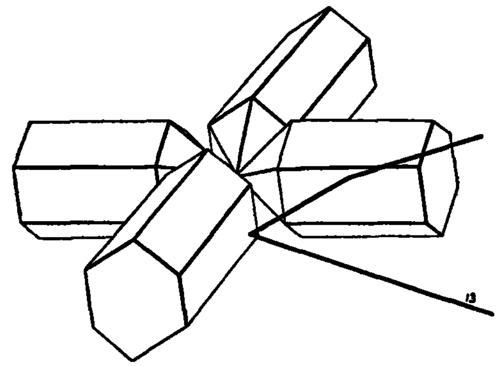

FIG. 13.—A possible combination of ice crystals which would produce the anthelion, the parhelia of 46°, etc.

The oblique arcs of the anthelion.

This is a very rare phenomenon, and its appearance in the present case on two successive days over the same region of the globe is truly astonishing. In 1850, when Bravais published his memorable works on halos, only 13 observations of this phenomenon were known. Since that time the number has been increased by 4, the last having been that observed by Brentano, at Ede, Holland, in 1900. Bravais proposed a very plausible and interesting explanation, as follows: Ice crystals often present on their faces parallel striæ. The arcs in question might be due to the dispersion of light by striæ of this nature occurring on the faces encountered by the rays which produce the anthelion. They would be arcs of small circles of the celestial sphere. The centers of these circles would remain at a constant distance from the zenith, but would shift in azimuth according to the altitude of the sun. Unfortunately, the observations do not agree well with this theory, with respect to the trajectories of the arcs in the sky. Among the data suitable for determining the trajectories, those which may be especially noted, are:

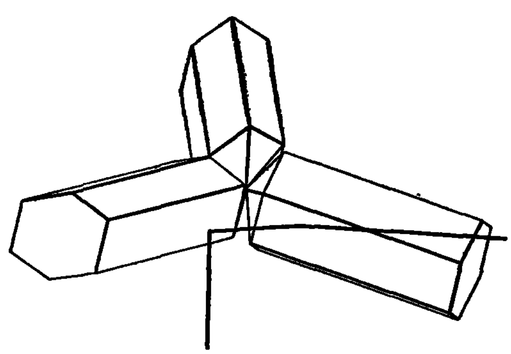

FIG. 14.—A possible combination of ice crystals which would produce the paranthelia of 120°, parhelia of 46°, etc.

1. The inclination of the arcs to the horizon, or the angle which they make with each other at their point of intersection at the anthelion.
2. The radius of curvature of the arcs.

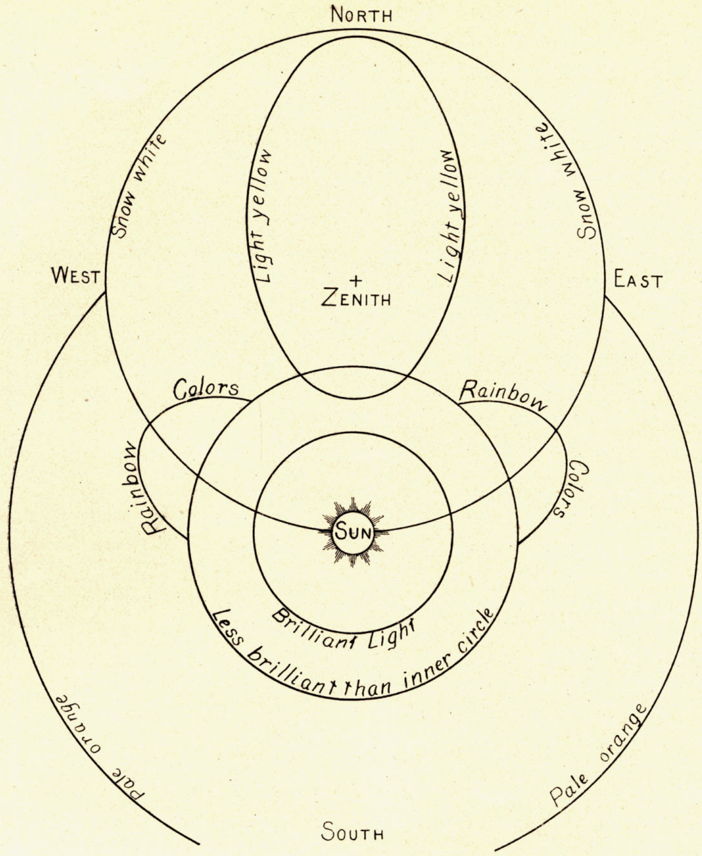

Fig. 9.—Halo observed at Dale Enterprise Va. ,by Mr. L. J. Heatwole, on Nov. 2, 1913.

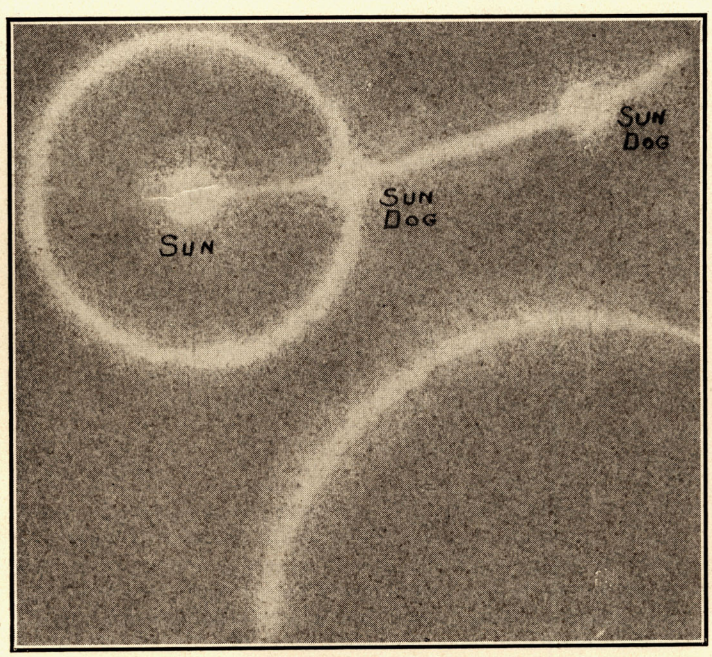

Fig. 10.—Halo observed at Staunton, Va., at 1 p. m. on Nov. 2, 1913, by J. C. Darnell.

3. The shortest distance of the arcs from the zenith.
4. The position of their second point of meeting on the side toward the sun.

The first element is difficult for the observer to determine, on account of the curvature of the arcs, and should be interpreted with caution. The second is no less difficult to determine, when the arcs are short. The third and fourth can be determined only when the arcs are of great length, but constitute much more definite criteria.

Let us consider especially the last. Before 1913 the arcs had been observed in 7 cases prolonged as far as their second meeting point, which in 4 or 5 cases had been found to be exactly at the sun. Now, according to Bravais's hypothesis, this meeting point could not coincide with the sun unless the latter were at the horizon, and it must have been far above the horizon in all the cases referred to.

The observations made in the United States on November 1 and 2, 1913, furnish some new information. From the drawings of Dr. Miller at Richmond, of Mr. Hazen at Springfield, of Mr. McGrew at Galena, and of Mr. Heatwole at Dale Enterprise, certain approximate measurements can be made, which it will be interesting to compare with the indications furnished by the theory. The solar altitude calculated from the hour of observation was between 37° and 38° in 4 cases.

Angle between the arcs.—Theoretical value, 101°–102°; Richmond, 106°; Springfield, 95°; Dale Enterprise, 180° (?); Galena, 47°.

Radius of curvature.—Mr. Hazen estimates that the arcs seen at Springfield were arcs of circles "of greater diameter than the circle parallel to the horizon." This observation is not in accordance with the theory, for the radius of the parhelic circle must have been 52° and that of the oblique arcs should have been, theoretically, 45°.

Minimum zenith distance.—Theoretical value, 15°–16°; Richmond, 27°; Springfield, 26°; Dale Enterprise, 20° (?).

Zenith distance of the second meeting point of arcs.—Theoretical value, 65°; Richmond, 59°; Dale Enterprise, 64° (?).

In the drawing of Dr. Miller, of Richmond, it is noted that the part of the arc situated on the side toward the sun had a greater curvature and a less intensity than the rest. One might inquire whether this part of the curve was not really an extraordinary tangent arc at the summit of the halo of 22°, fortuitously joining the oblique arcs and appearing to be a prolongation of them. On the other hand, it is noted that at Franklin, W. Va., these arcs appeared to meet at the sun.

In short, it is not possible to draw very definite conclusions from these observations. It is greatly to be desired that whenever the oblique arcs of the anthelion are again seen they should be subjected to exact angular measurements, and the same may be said of such other rare phenomena as the paranthelia of 90°, the halo of Hevelius, the parhelia of 46°, etc.

ADDITIONAL REPORTS.

Peoria, Ill.—A solar halo was observed on November 1, 1913, about 4:25 p. m. It was the usual 22-degree circle without marked brilliance or other unusual feature, except that the illuminated band was wider than usual. The 1st was a clear day, with cirro-stratus moving from slightly north of due west, appearing in the southwest and southern sky in the late afternoon and covering about one tenth of sky at 4:30 p. m. There were also a few of the same clouds near the northwest horizon.—*M. L. Fuller, Local Forecaster.*

Pensacola, Fla.—On November 1st a solar halo was observed at 9:45 a. m. It was partly cloudy from 6 a. m. to 8 a. m., cloudy with upper clouds from 8 a. m. to 11 a. m., partly cloudy from 11 a. m. to 12:30 p. m., then clear past sunset. * * * There were no unusual characteristics in our halo of the 1st.—*Wm. F. Reed, Jr., Local Forecaster.*

Memphis, Tenn.—A solar halo was observed at this station on November 1 at 3:30 p. m. On November 2 there was no halo observed. There is nothing recorded to show that there was anything unusual or remarkable in the appearance of the halo on the 1st.—*S. C. Emery, Local Forecaster.*

Macon, Ga.—None [no halo] was observed here on the 1st, but on the 2nd the phenomenon was seen clearly. It was first noticed in the morning from 10:50 a. m. to about 11:15 a. m. Owing to partial cloudiness which prevailed at that time near the sun, it was only a part of a circle and quite faint. But in the afternoon from 1:40 p. m. to about 3:30 p. m. it was very clear and distinct, a perfect circle most of the time of white light, of about 22° radius. At about 3:30 p. m. the clouds became very dense and it disappeared. Nothing peculiar or unusual was observed in connection with it.—*W. A. Mitchell, Local Forecaster.*

Charleston, S. C.—Bright solar halos of 22° radius were observed on November 1 and 2. That on the 1st occurred from 3 p. m. to 4:30 p. m. and was bright with distinct narrow rim, showing the colors plainly. That on the 2nd lasted from 9:30 a. m. to 5 p. m. and was remarkable for the brilliance of the primary colors, red, green, blue, and the distinct narrow rim. It was much brighter on the segment nearest the zenith and the green was exceptionally vivid. About 4:30 p. m. "sun dogs" were observed north and south of the sun but they were indistinct, being obscured somewhat by alto cumulus clouds. There was a faint lunar halo with no unusual characteristics from 6:40 to 7:50 p. m. of the 2d.—*J. H. Scott, Local Forecaster.*

Houston, Tex.—A solar halo of 22° radius was observed at 1 p. m. November 1, 1913. While plainly visible, nothing unusual was noted. The character of the day was partly cloudy with 0.7 clouds.—*B. Bunnemeyer, Section Director.*

Corpus Christi, Tex.—There was only one solar halo observed at this station. It was first noticed at 12:50 p. m., 90th meridian time, of [November 1]. Forming an uninterrupted circle of no more than 15° radius around the sun, the halo was well defined in colors. No other section of the halo was discovered. A thin layer of alto-stratus clouds covered the sky near the sun at the time. The halo faded away about 2 p. m.—*W. F. Lehman, Observer.*

Augusta, Ga.—On [November 2] the sky was cloudy with cirro-stratus clouds throughout the day and a well-defined solar halo was observed late in the afternoon. There was, however, nothing remarkable or unusual about this halo.—*E. D. Emigh, Local Forecaster.*

Washington, D. C.—At about 3 p. m. of [November 2] at my home in Washington, D. C., I observed a very brilliant solar halo consisting of the usual circle of about 22° radius, a white horizontal band passing through the sun, and brilliant parhelia where this band cut the 22-degree circle on either side of the sun. * * * It was the most perfect solar halo I had ever observed. So far as I can remember, it is the first halo in which I have observed the white horizontal band distinctly.—*Herbert H. Kimball, Professor of Meteorology.*

Columbus, Ohio.—No halo was observed at this station and we find no report of it in the file of the local papers.—*J. Warren Smith, Professor of Meteorology.*

[In reply to a circular letter sent by Prof. Smith to the Weather Bureau coöperative observers in Ohio, reports were received of the appearance of solar or lunar halos, for the most part inconspicuous, on or about the dates in question at a number of places in the eastern half of the State.]

Fort Smith, Ark.—Mr. L. J. Guthrie, Local Forecaster, sends a drawing of a halo seen on October 31, consisting of the circumzenithal arc and the two parhelia of 46°.

THE DIFFERENT FORMS OF HALOS AND THEIR OBSERVATION.[1]

By Louis Besson, Observatoire de Montsouris.

[Translated by Cleveland Abbe, jr., May-June, 1914.]

INTRODUCTION.

Halos are optical meteors produced by the light of the sun or of the moon, in clouds composed of ice crystals. They consist of curves or of luminous foci, either white or tinted with prismatic colors. The remarkable brilliancy they may attain, the extreme variety of their forms, and the somewhat fantastic character of their appearance, make their observance and study most interesting. For these reasons numbers of astronomers and physicists have paid particular attention to them at different times. We owe memorable descriptions of halos to Hevelius. Tycho Brahe observed them carefully at Uraniaborg for 16 years. Among the chief we may mention Huyghens, Mariotte, Fraunhofer, Young, Venturi, Galle, as having studied this class of phenomena and labored more or less successfully to establish a theory of them. The theory was, however, still quite imperfect when Bravais took it up toward the middle of the last century. In a masterly memoir he so far perfected and completed the theory that he seemed to have indeed succeeded in quite satisfactorily explaining all the known forms of halos.

In fact, even today the theory cannot be regarded as other than a more or less probable hypothesis for a very large number of the forms, because existing observations are generally far too few and too inexact to furnish a satisfactory check on the results of computation. This is why the Austrian physicist Pernter, in his recent treatise on meteorological optics, could plausibly reject the Bravais theory relating to three kinds of tangent arcs of the 46°-halo, and substitute another theory which gives them quite different forms.

On the other hand, there is a whole class of extremely rare halos which have been observed but once or twice and remain wholly enigmatical. Not only is their explanation still imperfect, but it will be a long time before we shall have a complete list of their forms. We still have rather frequent reports of combinations and forms that have never been reported during the centuries that have past, and it may be supposed that many unknown forms still await observation.

Halos will, therefore, long offer a fertile field of investigation. Observers should be made aware of this fact in order that a larger number of persons may turn to this field of study. In fact our knowledge of halos can not advance at all rapidly unless numerous persons located at many points on the globe shall observe them. No individual observer, however vigilant throughout his life, can see more than a fraction of the total possible forms of halos. The well-known French meteorologist Renou watched ceaselessly for halos during more than half a century, nevertheless he never saw the oblique arcs of the anthelion, nor the halo of Hevelius, nor the paranthelia of 90°, not to mention many another rarer phenomenon.

From time to time every assiduous observer will find his pains rewarded by his being the first to make some angular measurement or some important discovery; but he will never be able to elucidate more than a portion of the subject by means of his own unaided observations. On the other hand, if there are numerous observers in each country paying intelligent heed to the halos occurring, there can be no doubt that in a few years many uncertainties and gaps will disappear from the theory of these phenomena. Indeed many of their forms, though extremely rare at any given place, probably occur often enough at one place or another upon the earth. * * *

As a matter of fact, the observations on halos published in scientific works are quite inadequate, both as regards quantity and quality. The majority of them are quite devoid of interest since they pertain to phenomena which the observer thought extraordinary, but were really nothing other than more or less brilliant manifestations of known phenomena. Sometimes there are among the described forms, curves whose form is not yet well defined or that appear to be new ones. Unfortunately the descriptions of those portions of the phenomenon whose identity is undoubted almost always reveal such inaccuracies that they greatly weaken our confidence in the observer's other descriptions.

In most cases the observer is a man of science. Often, indeed, he is skilled in the most delicate measurements of physics or of astronomy. If his observation is bad or has not the value that should attach to it, the reason is that he was not familiar with this very special class of phenomena. One observes but poorly that with which one is unacquainted.

Here as in everything else, if one is to do useful work in studying halos it is indispensable that one shall be well acquainted with them and practiced in observing them. Unless one may profit by lessons from an experienced observer for some little time, it is not easy to acquire this practical knowledge. True, various works on meteorology or on general physics present more or less complete lists of halo forms, and a more or less detailed exposition of their theory. None of these sources, however, offer the beginner that practical guidance which would help him to seize in transit, so to speak, these generally fugitive phenomena, and to recognize their often incomplete or indistinct forms. * * *

Having pointed out the insufficiency of halo observations and the advantage of multiplying and improving them, it is now in order that I should facilitate the task of persons disposed to undertake observations and should indicate to those already engaged points to which they should particularly direct their attention.

What are halos?

We shall now pass in review the various known forms of halos, beginning with those of most frequent occurrence and the easiest to perceive.

[1] Besson, Louis, Les différentes formes de halos et leur observation. *Extrait du* Bulletin de la Société astronomique de France (mars, avril et mai 1911). Also published separately Paris. [1911?] 22 p., 20 figs. 8°.